UCAR/COMET: 6 Month Outreach Project Report: January 19, 2006
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Assimilation of Multi-Satellite High Resolution Sea Surface Temperatures for a Real-Time Local Analysis and Forecasting System.

Accomplishments pertaining to the project tasks, as delineated in the proposal for *Year I*, were summarized in the annual report in May 2005. Year II project goals as stated in the original proposal are given as follows:

-Use MODIS variance statistics to aid in development of SST analysis weights
-Use GOES-12 variance statistics to develop SST analysis weights
-Continue/complete ADAS development of SST analysis
-Compare ADAS/ARPS select short-term simulations with/without high resolution SST analysis
-Transfer software to NWS
-Submit FIT/NWS publication(s) to Weather Analysis and Forecasting

Bold indicates task is near completion. These are addressed individually within this summary.

1. Project Information, Objectives and Accomplishments: Year II

1.1 Academic and Forecast Partners

a. Corey Calvert, an M.S. graduate student, has been working in support of this project since its inception in June 2004. The student has been paid under this grant and is currently finishing his MS work (he is scheduled to finish by February 2006). He will continue to be supported by the project after his graduation during which time he will assist in the following tasks: 1.) prepare a publication, 2.) complete work on an operational SST analysis system, and 3.) transition software to the NWS.

b. As reported in the 1 year summary (May 2005), an "end-to-end" analysis system has been configured (using the analysis methodology of ADAS, Bratseth 1986). In addition to the analysis algorithms, the 'processing' components of the new system were listed as follows:

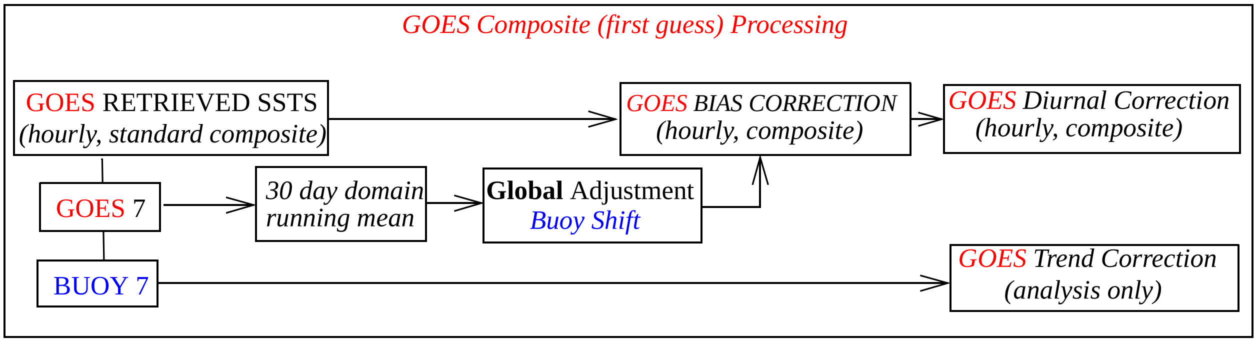
1. Scripts for the real-time processing of the RTG-SST, GOES-12 and MODIS SSTs
2. Algorithms that merge 1 km MODIS SSTs with a separate geolocation file and subsample the HDF files for SST data within the ADAS domain.

In an attempt to QC the GOES data stream, we have added an <u>additional</u> sun glint mask for the GOES-12 data (see Problems Encountered/General Issues section for details).

c. We have selected a trial period (May 2004) from which to derive analysis statistics for evaluation and tuning purposes. In an effort to remove biases from both the background field (GOES composites) and observations (MODIS), average diurnal SST timeseries for May 2004 over the Florida ADAS/ARPS domain were generated. Because there are relatively few buoy observations, there remains an issue of representativeness. As a result, we show timeseries for <u>both</u> the domain-wide and buoy co-located (i.e., nearest neighbor) MODIS (separated by platform) and GOES-12 SSTs (Figure 1). The buoy and GOES/MODIS collocated time series were taken from a 30 day average at the 7 'available' buoy locations within the ADAS/ARPS domain (41009, 41010, 41012, 42013, 42022, 42036, and SGOF1). A more complete discussion of how these various time series are used in the bias correction process follows.

GOES (background) Adjustments

The domain-wide GOES time series (derived from zero latency GOES files) compares favorably (with respect to the diurnal trend) to that of the buoy co-located GOES (red versus gold diamonds respectively). However, the buoy (and GOES co-located) observations are cooler than the domain-averaged GOES. To produce domain-representative SST bias corrections, buoy SSTs are first 'shifted' (black open circles) by an amount equal to the average difference between the domain-wide and buoy co-located GOES time series. The zero latency GOES data (for May 2004) are then bias corrected hourly using the adjusted buoy data. After the zero latency GOES data are bias corrected, the data are then composited to produce a background field (analysis first guess). The bias corrected composites, which can have widely varying latencies due to clouds and sun glint, are then adjusted by applying a 'diurnal correction' (e.g., see Lazarus et al. 2006, Gentemann et al. 2003 for details). The diurnal time series for this product is represented by the cyan triangles in Figure 1. Comparison with the composite product that does not undergo a bias or diurnal correction (herein referred to as the 'standard' composite, pink open squares) indicates that the corrected composite product is 1.) more smoothly varying (like its buoy counterpart), 2.) generally cooler than the non-adjusted composites, and 3.) more closely matches the diurnal trend exhibited by the average of the seven buoys. The bias correction removes the SST spike that appears in both the zero latency GOES domain-wide and co-located timeseries around 5 UTC (this feature is ostensibly associated with instrument recalibration, Maturi personal communication). The bias and latency corrections also remove a less pronounced SST spike around sunrise while the diurnal correction mitigates the impact of the GOES data gap (15-19 UTC) associated with sun glint. The composite timeseries will, in general, be cooler than the zero latency timeseries because May is a month in which the SSTs climatologically warm. The bias corrected composite is, for most hours, cooler than the standard composite because the adjusted buoy timeseries is cooler than the GOES zero latency. Because of this, the bias corrected composite *may* (**we are in the process of determining what the best approach is here**) undergo a second hourly 'trend' correction based a on 30-day running mean diurnal buoy timeseries. The sequence of adjustments to the retrieved GOES SSTs are shown in the flow chart below.



MODIS (observation) Adjustments
We also show the domain-wide (green diamonds) and buoy co-located (yellow squares) MODIS SSTs in Fig. 1. With the exception of the 16 UTC Terra overpass which appears to be too cool, the MODIS domain-wide SSTs compare favorably with the buoy co-located (blue triangles versus yellow squares). The problematic nature of the 16 UTC MODIS (Terra) data may be the result of limb (off-nadir) issues as the satellite traverses the periphery of the ARPS/ADAS domain at this time. Similar to the background field bias corrections discussed above, differences between the domain-wide and buoy co-located MODIS SSTs will be used to bias correct the MODIS data stream.

Operational QC/Bias Correction Summary:

Step 1: GOES additional glint removal.

Step 2: GOES removal in shallow waters during day: remove if 15m < z < 25m.[1]

Step 3: Update: 30 day average multiplatform comparison

Step 4: Create Composites (with diurnal and bias correction)

i. Multiplatform Bias Correction:

Remove 15-21 UTC GOES SSTS

ii. Diurnal Correction (Gentemann et. al 2003)

Inputs: GOES solar + recent wind analysis (e.g. NCEP NAM)

Step 5: Analysis

iii. 4 times/day analysis at MODIS times?[2]

d. A second conference preprint and presentation "*Multi-platform real-time sea surface temperature analysis for the initialization of short-term operational forecasts*" will be presented at the 2006 Annual AMS conference. The authors correspond to those listed on this grant. This second paper focusses on quality control and the extraction of error statistics for a selected period (May 2004).

1. Will not be implemented for initial operational product.
2. The number of operational analyses will depend on the quality of the 16 UTC Terra overpass.

2. Related Accomplishments

a. *Significant* collaboration with the SPoRT facility in Huntsville AL continues. As part of a consulting agreement, the PI made 4 separate trips to Alabama during the fall (September, October, November and December). During the November visit, Dr. Lazarus gave a short presentation at the SPoRT Site Advisory Committee Review meeting. The status of these collaborations are discussed briefly below.

SST Composites (MODIS vs. GOES)
This work is an offshoot of the SST analysis work discussed herein. Various MODIS composites are currently being generated in near real-time (see http://weather.msfc.nasa.gov/sport/sstAnimation/). A version of these composites is currently being used in conjunction with WRF simulations (see next section) over the same test period as the analysis test bed (May 2004). An intercomparison with the FIT GOES composites is currently underway and will be presented at the AMS conference (Haines et al., 2006). Additionally, work on a publication (with the PI as a co-author) should begin sometime this spring with a target submission to IEEE Transactions on Geoscience and Remote Sensing. The publication will focus on an SST intercomparison of various products and observations including MODIS and GOES composites, NCEP's Real Time Global (RTG) SST analyses, buoy, and FIT analyses (for May 2004).

WRF/ADAS model simulations over Florida
This work is directed towards the evaluation of the impact of high resolution SSTs on short-term model forecasts (~ 24 h). SPoRT has now completed <u>all</u> of the forecast simulations for May 2004 (various images and animations are available on line at http://weather.msfc.nasa.gov/sport/may04sst/). FIT is also constructing a website (see: http://my.fit.edu/~msplitt/sport/may_2004.html) that provides regional weather forecast summaries (obtained from the National Weather Service), and WRF output combined with observations (scatterometer, buoy, and mesonet). The 24 h WRF/ADAS simulations include two runs per day (one with high resolution MODIS composite SSTs and the other using NCEP's RTG SST analysis). Details of the model configuration etc. are available in LaCasse et. al (2006). Highlights/impacts of the model simulations include:

Onset of horizontal convective rolls
It appears as if the high-resolution SST simulation (with MODIS composite SSTs) may play a role in the timing of the onset of HCRs with earlier initiation for the high-resolution SST simulations. These results are reported in Lacasse et. al (2006).

Impact on 10 m wind field
Recent work examining model output winds from European Centre for Medium Range Weather Forecasts (ECMWF) has shown that higher resolution SSTs can significantly impact the surface wind stress field (Chelton and Wentz 2005; O'Neill et al. 2005, Chelton 2005). An example of the WRF 10 m wind response for the 14 May 2004 simulation (shown in Fig. 2a) illustrates the impact on the low level wind fields off the central east coast of Florida for a case of predominately low-level easterly flow. Regional SST differences between the MODIS and RTG SST simulations approach 2 K (RTG minus MODIS, color contours). The SST insertion is static, i.e.the SSTs are not updated over the course of the 24 h simulation. The wind field response to the high-

resolution SSTs is on the order of +/-0.6 ms^{-1} with the differences resulting from enhanced (decreased) boundary layer mixing as a result of the warming (cooling) of the SST -- which occurs predominantly in the significant gradient regions. The impact of the high-resolution SSTs on the boundary layer circulation can be seen in the vertical cross-sections of wind speed and relative humidity (RH) differences (RTG minus MODIS) taken along the white segment in Fig. 2a (Figs. 2b and 2c respectively). For the high-resolution simulation, over the warmer SSTs the boundary layer is deeper with higher wind speeds near the surface (i.e., dashed/negative contours indicate that MODIS wind speed > RTG wind speed) and decreased winds above. Conversely, over the cooler SST regions we see a decrease in boundary layer depth and the reverse in the wind field -- with decreased winds near the surface and increased aloft as a result of decoupling.

It is also anticipated/expected that we will begin to write (sometime this spring) an article for the above-mentioned WRF simulation work.

b. As of the 1 year report the PI had just finished writing a joint NASA proposal with SPoRT and the University of Alabama Huntsville, UAH. The proposal title: “An Improved Data Reduction Tool in Support of the Real-Time Assimilation of NASA Data Streams” was funded and will evaluate the impact of identifying and removing redundant SST data on the SST analyses.

c. As part of his summer 2004 visit to NCEP, the PI acquired a two-dimensional version of the NCEP grid point statistical interpolation (GSI, Wu 2002) which is under development/testing as part of NCEP’s Unified analysis system (i.e., one analysis for both their regional and global forecast systems -- see http://www.emc.ncep.noaa.gov/research/NCEP-EMCModelReview2004/EMC-Preliminaries.pdf for more). During the summer of 2005 the PI tried, unsuccessfully, to run the code on the FIT Beowulf cluster. While the code compiles, there are some portability issues with respect to message passing that have yet to be worked out. Eventually, it is hoped that this code will serve as the operational component of the 2DVAR system here at FIT.

3. Summary of Benefits

3.1 Academic Partner

a. This project has led to a collaboration with SPoRT which has thus far produced:

i. 4 conference papers
ii. formal collaboration (consulting and subcontract work)
iii.1 funded proposal
iv. discussions involving future collaborations
v. employment of the PI’s former FIT graduate student

b. The COMET financial support provided by this grant is serving as the primary research component for Mr. Calvert’s Masters degree which is nearing completion and will be made available to COMET.

c. The work has led to collaborations with both NESDIS and SSEC personnel and has identified several problems with both (MODIS and GOES) operational SST data streams.

3.2 Forecast Partner

a. Potential future line of cooperation between WFO Miami/Melbourne, FIT, and SPoRT could include a model *intercomparison* of the impact of the high resolution SSTs between the WRF/ ADAS (SPoRT) and WRF/LAPS (WFO Miami) systems. This proposed additional work would represent an effort to “piggy-back” on Dr. Lazarus' current project while trying the maximize the return of much smaller COMET Partners project such as the one between WFO Miami and UNC Charlotte. Additionally, it is worth mentioning that the WFO Miami was the beneficiary of some pro bono work from FIT personnel (Corey Calvert and Dr. Lazarus). Within the last year, FIT transferred (to the Miami WFO) an in-house algorithm that processes near real-time GOES data to produce high resolution SST composites (this work was documented in a previous COMET-funded partnership proposal by the PI). The Miami and Melbourne WFOs are now generating the composites locally and ingesting them into their operational AWIPS systems. The output grid files are also being shared with WFOs Tampa and Key West. The composite algorithm has also been transferred to the WFO in San Juan, PR, allowing them to composite high resolution SSTs locally across their domain. In addition to the WFO AWIPS ingest of the composites, the WFO Miami is using the composites in their IFPS to assist in the creation of hourly graphical products that are then disseminated via the web and wireless devices.

b. This project remains consistent in the direction toward the exceptional use of high-resolution local modeling in support of WFO tactical meteorological operations as envisioned by the participating WFOs. The consistent and coherent assimilation of quality multi-satellite derived SSTs is leading toward improvements in near real-time coastal and marine mesoscale analysis and short-term forecasting, while addressing important matters such as managing data volume and latency, quality control, and bias correction routines for satellite data. At WFO MLB, the ADAS continues to operationally mature with an expanded domain which now encompasses all of the Florida coastal waters to include the lower keys and the western panhandle. Due to geography, this larger domain has acquired a substantial marine area over the eastern Gulf of Mexico which will rely heavily upon multi-satellite data observations for generating reasonable SST analyses. Additionally, WFO MLB is poised to begin the gradual transition from ARPS to WRF as the preferred operational local model. Knowledge and experience gained, both directly and indirectly, will foster a smoother transition for an ADAS/WRF configuration.

c. It was previously noted (Year I COMET report) that the forecast partners have replaced the course resolution RTG_SST within the Melbourne ADAS/ARPS with the GOES composites. It was anticipated this would improve the overall quality of the ADAS analyses and short-term ARPS forecasts over peninsular Florida. This *may* still be the case during the cool months -- however, there are relatively <u>significant</u> QC issues with the **warm** season GOES SST composites that are used to initialize the ARPS/ADAS forecast cycle in Melbourne (see Section 5.2 for more). *We anticipate that at the time of this report, the “standard” composites will be replaced by a much improved SST analysis prior to the onset of the warm season.* These SST analyses will be made available to the WFO Miami for their continued work with the WRF/LAPS system and to the other Florida WFOs for nowcasting, and to assist in populating the IFPS. As some of the results reported herein suggest (e.g., HCRs, PBL response, etc.), we believe that it is critical that forecasters have an increased understanding of the nuances associated with thermal SST gradients, SST/LST contrasts, and that improved SST products will eventually translate into better analyses and short-term forecasts. The forecast partners are also nearing the creation of an (independent?) SST product via their Local Digital Forecast Database (LDFD). An experimental LDFD SST product is currently being provided by the WFO in Miami (see http://www.srh.noaa.gov/mfl/analysis/). This product is consistent with NOAA's gridded/graphical forecast products.

d. In our Year I report, it was mentioned that both WFO Melbourne and Miami had a relatively well-established relationship with SPoRT and were slated (in 2005) for receipt of several SPoRT-generated value added products from the MODIS platform. While some of these products have been delivered (e.g., LST), others have not -- however the PI has had recent discussions with Dr. Jedlovec (SPoRT) regarding collaborative work involving the implementation of the remaining SPoRT MODIS products and the regional expertise at FIT. The COMET project has engendered a good deal of familiarity (within the regional NWS offices) with the MODIS (and GOES) data streams and are thus primed to receive these (and other future NPOES streams) into their respective operations.

4. Presentations and Publications

a. The PI gave a 15 minute talk at the SPoRT Site Advisory Committee meeting 21 November 2005 in Huntsville Alabama: *Evaluation of Near Real-Time Composites and Analyses*.

b. The PI is scheduled to present at the 2006 AMS annual conference (Atlanta, GA): *Multi-platform Real-time Sea Surface Temperature Analysis for the Initialization of Short-term Operational Forecasts.*

c. Preprint 2005 AMS conference: *Assimilation of multi-satellite high resolution sea surface temperatures for a real-time local analysis and forecasting system.* January 2005.

d. Conference Preprints (chronological order):

Haines S. L., G. J. Jedlovec, S. M. Lazarus, and C. G. Calvert, 2006: An Aqua MODIS sea surface temperature composite product. Preprints, 14th Conference on Satellite Meteorology and Oceanography, Atlanta GA, Amer. Met. Soc., January 30-February 2, 2006.

LaCasse, K., M., W. M. Lapenta, S. M. Lazarus, and M. E. Splitt, 2006: The Impact of MODIS SST Composites On Short-Term Regional Forecasts. Pre-prints, 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, Atlanta GA, Amer. Met. Soc., January 30-February 2, 2006.

Lazarus S. M., C. G. Calvert, M. E. Splitt, P. Santos, D. W. Sharp, P. Blottman, and S. Spratt, 2006: Multi-platform Real-time Sea Surface Temperature Analysis For The Initialization Of Short-term Operational Forecasts. Preprints, 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, Atlanta GA, Amer. Met. Soc., January 30-February 2, 2006.

Calvert, C. G., S. M. Lazarus, P. Santos, D. W. Sharp, P. Blottman, and S. Spratt, 2005: Assimilation of Multi-Satellite High Resolution Sea Surface Temperatures for a Real-time Local Analysis and Forecasting System, Preprints, 16th Symposium On Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, SanDiego California, Amer. Met. Soc., January 9-13 2005.

Etherton, B., P. Santos, S. Lazarus, and C. Calvert, 2004: The effect of using AWIPS LAPS and High Resolution SSTs to locally initialize the Workstation Eta. Submitted to extended abstracts of the 9th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, 85th AMS Annual Meeting, San Diego, CA, January, 2005.

5. Problems Encountered/General and Remaining Issues

5.1 Academic Partner

a. It was stated in the Year 1 summary (submitted last May) that quality control of the data streams (GOES-12 and MODIS) remains a priority (and must precede analysis error variance and length scale estimates). Since then, the majority of project hours have been spent examining the data quality and bias removal (for more on the latter, see Section 1.1 GOES Background Adjustments). Here, we summarize various (and significant) QC issues as they pertain to each data stream individually.

GOES SST QC

Some *significant* and problematic issues have surfaced in the GOES data stream. These issues involve SST contamination due to 1.) sun glint and 2.) bottom reflectance and are discussed below.

> **Sun Glint** - Although the GOES data stream provided by NESDIS allegedly contains flags for cloud and glint contamination, glint contaminated data remain in the operational data. This issue was originally discovered via the composite intercomparison work with SPoRT (see Haines et. al, 2006) and produces spuriously warm SSTs -- especially in the Florida coastal waters (see Figure 3). Because this problem was discovered prior to (but now appears to be related to) the bottom reflectance issue (see below), we still had anticipated using the ‘available’ daytime GOES observations and as a result, the GOES data were <u>reprocessed</u> using a second glint algorithm.
>
> **Bottom Reflectance** - In our effort to remove bias from the data we examined the innovations (i.e., background minus observations) for May 2004. It can be problematic to remove bias in the background or observations if the bias is spatially dependent. Following the removal of the residual glint, as discussed above, we continued to observe spuriously warm SSTs which appeared to be associated with the shallow (coastal) shelf regions of our domain. Figure 4 is combination of related figures including the regional bathymetry (Fig. 4a), MODIS minus GOES SSTs as a function of depth and stratified by day (red x’s)/night (black/green dots, Figs. 4b and 4c), and the spatial distribution of the GOES warm bias (Fig. 4d) for data within the blue circle shown in Fig. 4c. It is clear from these figures that:

i. The nighttime innovations are relatively constant with respect to ocean depth and are on the order of 0.5^{o}C (with the MODIS being warmer, dashed line Fig. 4b).

ii. The daytime innovations indicate a distinct bimodal distribution at depths between 15 and 25 m with a significant number of warm GOES SSTs (negative bias, oval circle Fig. 4c).

iii. The warm daytime GOES data (blue circle, Fig. 4c) are found exclusively within the shallow coastal shelf regions (Fig. 4d).

Albeit a bathymetric bias correction is possible, it is not certain under what conditions (e.g., sun angle, water turbidity, etc.) this could be effectively applied. *As a result, at the time of this report, we are planning to remove all GOES data between the hours of 15 and 21 UTC*.

MODIS SST QC

We have identified two primary issues regarding the MODIS SST data quality -- namely 1.) spurious glint and 2.) an apparent limb effect contributing to cool SSTs for the 16 UTC Terra swath. These issues are discussed in more detail below.

Sun Glint - According to the retrieval algorithms described in the paper "The IMAPP Sea Surface Temperature Algorithms", the daytime MODIS SSTs are calculated using the longwave IR channels (i.e., 10/11 µm) only (unlike the GOES which also uses the 4 µm channel). If this were the case then glint should not be an issue. However, live broadcast MODIS data from SSEC often appears to contain a significant amount of glint contaminated pixels (compare Figs. 5a and 5b). After an E-mail exchange and phone call an error in the live broadcast SST algorithm was identified and removed (K. Strabala, personal communication).

Limb Effects - As discussed in Section 1.1 (item C), the 16 UTC Terra overpass appears to be too cool and may be the result of limb (off-nadir) effects in the instrument as the satellite traverses the periphery of the ARPS/ADAS domain. Because the satellite skims the domain at this time, the data files are often small and will thus not be used in the operational analyses until a more sophisticated QC algorithm can identify and remove the offending data.

b. Error covariance estimation is critical - and difficult if not impossible to determine. In order to obtain representative error variance estimates -- *bias must be removed*. We intend to use the sum of the squares of the local innovations (MODIS minus GOES) to produce a monthly (and spatially) varying error climatology. Here, 'local' implies the use of innovations within a specified region (on the order of 80 km radius). Because of the computational expense, the error variance will be estimated for every 10th grid point and then 'spread' to the remainder of the analysis grid using the Barnes (1964) approach. See Lazarus et. al 2006 for more.

c. Length scales will also be determined using a similar approach described above for the error covariance estimate. A distance-dependent correlation between local innovations will be calculated (also using data over a month period -- see Lazarus et al. 2006 for more). Because the number of innovation pairs can be quite large (total goes approximately as the square of the number of observations) we intend to concentrate the calculations in specified regions of interest (i.e., regions with significant SST gradients) which will then be spread throughout the analysis grid in the same manner as described above for the error variance. Preliminary tests indicate that the correlation estimates are robust and change only gradually over distances on the order of 100 km.

d. Data availability/latency remains an issue. The PDFs that we are now generating in association with the GOES composites are providing a hourly distributions - however it is not clear how to deal with extended drift as the diurnal correction methodology does not adjust the SSTs sufficiently to account for longer SST trends.

5.2 Forecast Partner

a. The forecast partners have successfully replaced the RTG_SST within the ADAS/ARPS with GOES-only composites. Given the identified issues with sun glint and bottom reflectance during the day, WFO MLB is currently determining the best operational strategy until an interim solution is found or the multi-satellite SST composites are fully realized and implemented.

6. References

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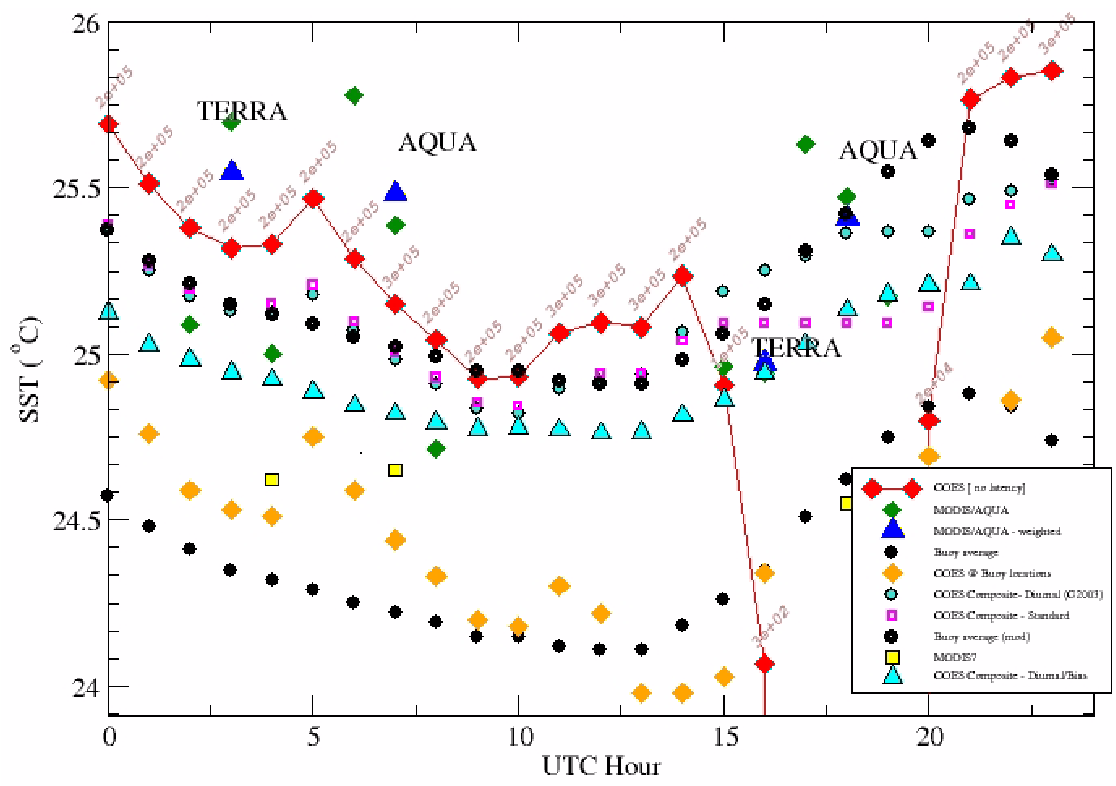

Figure 1: Diurnal time series of sea surface temperatures (^{o}C) for May 2004. Shown in the figure are MODIS (labeled either Terra or Aqua, green diamonds or weighted/combined blue triangles), buoy co-located MODIS (yellow squares), domain-wide and buoy co-located zero-latency GOES SSTs (red and gold diamonds respectively), buoy and buoy adjusted (black circles filled and unfilled respectively, see text), GOES standard composite (pink open squares), bias corrected/ diurnally adjusted GOES composite (cyan triangles).

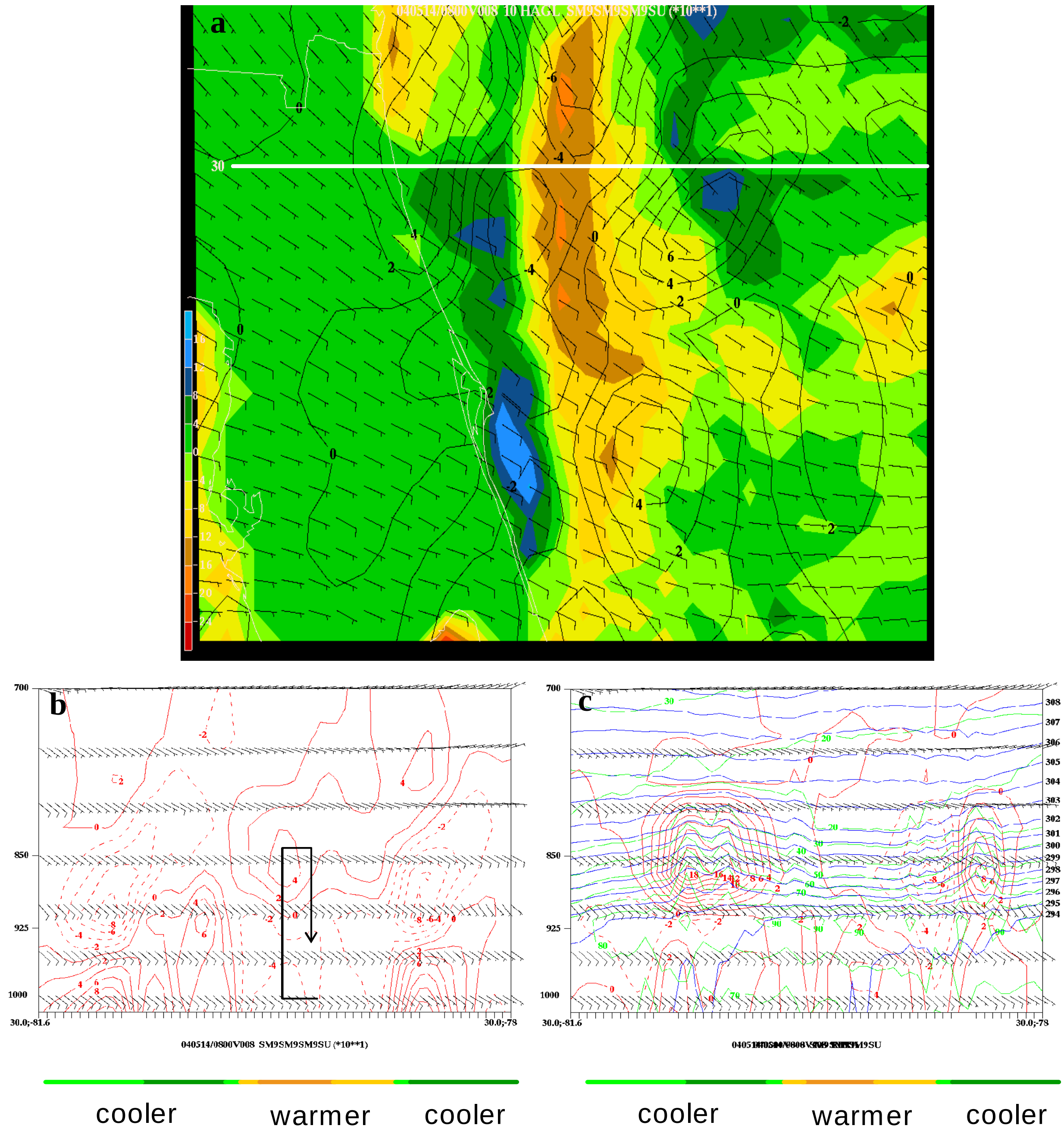

Figure 2: WRF simulation valid 08 UTC 14 May 2004 showing difference fields (RTG minus MODIS) for a horizontal cross-section a.) SST (color filled with a contour interval 0.4 K) and 10 m wind magnitude (solid lines with a contour interval of 0.2 ms^{-1}) and vertical cross-sections of b.) wind speed (solid/dashed red contours, interval 0.2 ms^{-1}), and c.) relative humidity difference (solid red contours with interval equal to 2%), MODIS SST simulation potential temperature (solid blue lines, 1K interval) and relative humidity (solid green lines, 10% interval). Wind barbs (ms^{-1}) on each figure are from the high-resolution SST (MODIS) simulations.

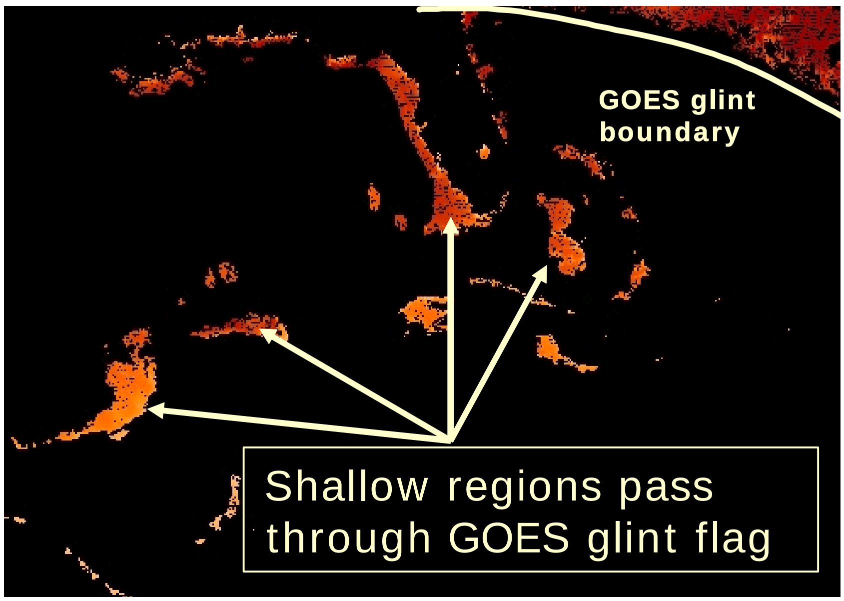

Figure 3: An example of the spurious glint-contaminated GOES SSTs. These data are not properly flagged in the NESDIS operational SST stream.

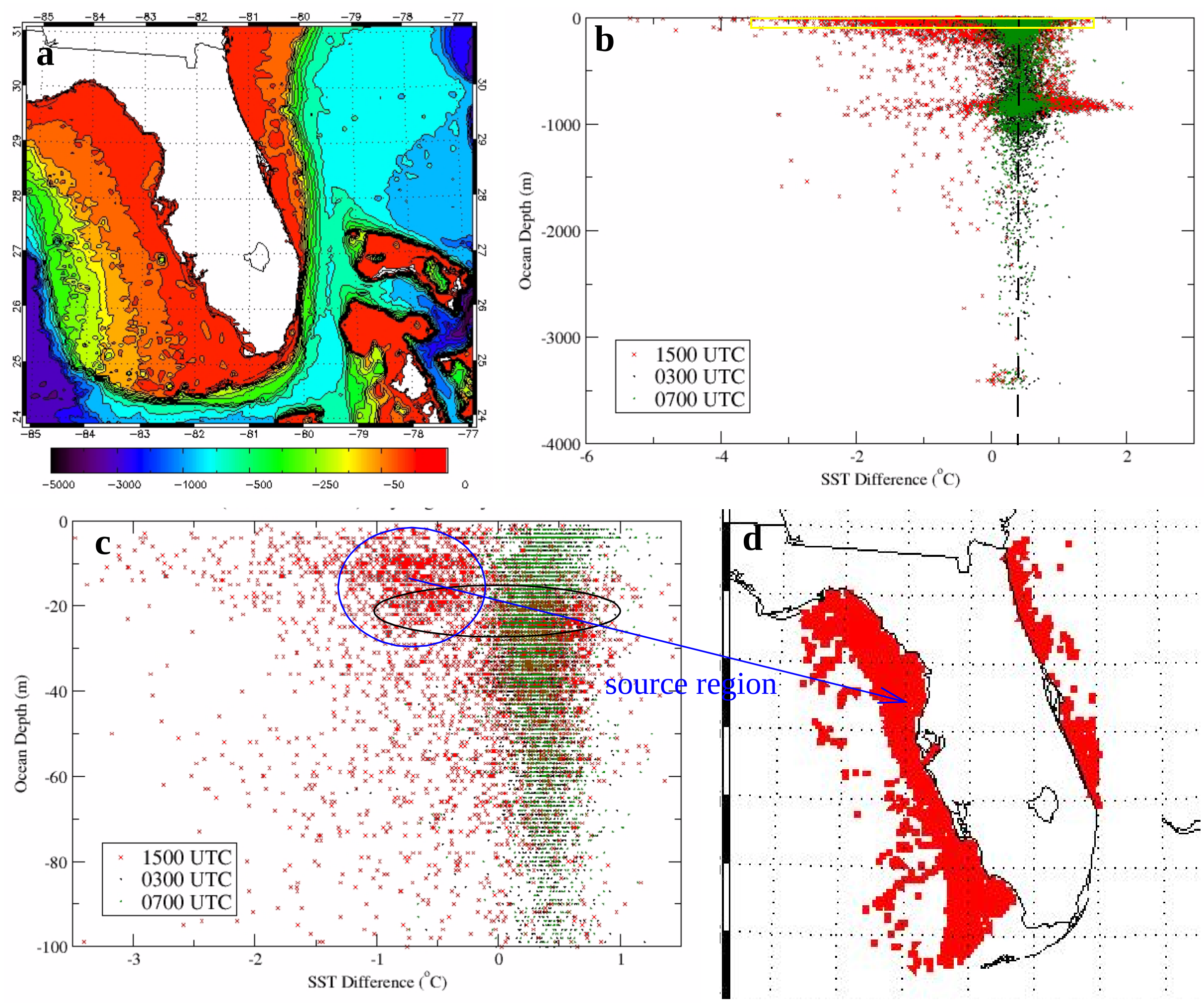

Figure 4: a.) Regional bottom bathymetry (m), May 2004 statistics b.) day/night (red crosses/ black or green dots) innovations as a function of bottom depth, c.) enlarged region given by the yellow box in Fig. 4b, and d.) the spatial distribution of the warm GOES observations from the blue circle region in Fig. 4c. See text for other details.

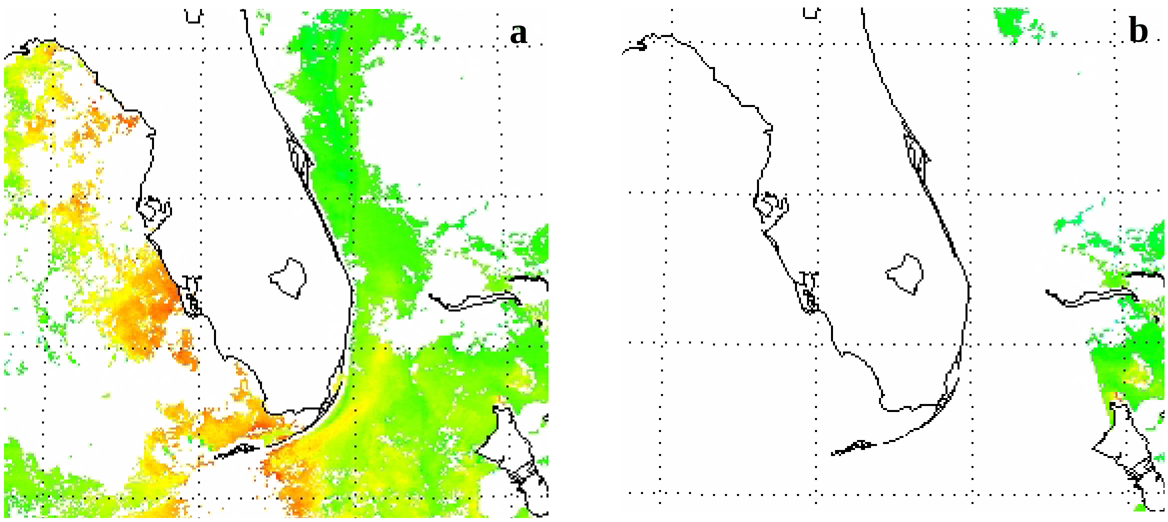

Figure 5: MODIS (Aqua) SSTs for 1835 UTC 3 August 2005 overpass with (a) and without (b) sunglint.